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Active Flow Control for Aircrafts and Heavy Vehicles

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by

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Abstract

Bluff-body flows are dominated by large dissipative vortex-shedding wakes with low mean pressure compared to the high pressure on their frontal area. This induced pressure difference is the major contribution to the total aerodynamic drag.

The objective of the present work is to apply Active and Passive Flow Control (AFC) strategies to reduce the typically large base drag on bluff-bodies. Two main cases are investigated: A tilt-rotor aircraft wing during hover and a simplified truck-trailer model. Numerical computations using large-eddy simulation of the turbulent flow are carried out with and without AFC in order to evaluate the achieved drag reduction. A thorough parameter study of a novel rear-end trailer geometry and the parameters of AFC is carried out and also optimized using Response Surface Methodology. Flow reattachment process, dynamics of the flow with and without AFC and corresponding wake structures are discussed and analyzed. Experimental investigation of a typical synthetic-jet actuator is also carried out in order to evaluate the order of magnitude of maximum possible momentum coefficient C_μ.

It is shown for with AFC the separated flow on the mounted flaps is reattached in the tilt-rotor aircraft wing and the truck-trailer model. The large dissipative wake size is narrowed and its intensity weakened. The base pressure is increased a great deal and the corresponding drag reduction is about 30% in both cases. The maximum possible momentum coefficient is $C_\mu = 1\%$ which is enough in order to achieve the desired drag reduction.

Keywords: Bluff-body, Wake, Active and Passive Flow Control, Drag reduction, Trucks, Heavy vehicles, Tilt-rotor wing, Aircrafts, Large-eddy Simulation, Response surface methodology, optimization, Synthetic-jet Actuator

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Contents

Background

ENVIROMENTAL requirements are becoming stricter, the international competition within heavy-vehicle industry is even harder during the current financial crisis, fuel prices are still increasing and the energy resources of the world are decreasing. The global warming problem due to greenhouse gas emissions is the hottest political debate question around the world. Carbon dioxide (CO_2), nitrous oxide (NO_x) and particulate matter (PM) are believed to be the main exhaust emissions that pollute and contribute to the global warming.

This thesis is aimed to present research on vehicle aerodynamics optimization in order to improve fuel economy and environmental performance. The focus is on aerodynamic drag reduction using active and passive flow control strategies. The aerodynamic drag is the major energy loss at high-way cruising speeds and the base drag is the dominant contribution to the total aerodynamic drag. The main idea is to increase the base pressure by adding flaps and reattach the separated flow on the flaps to narrow the wake size. The reattachment process is done by active flow control (AFC). The wake intensity is also weakened due to the creation of small vortices that rolls down the flap surface and prevents the interaction between the shear-layers of the wake.

Tilt-rotor Aircraft

The tilt-rotor aircraft has many benefits in comparison with a helicopter. Those include speed, range and payload. It has the helicopter's capabilities of vertical take-off and landing as well as the cruise speed, range and fuel economy of a fixed-wing aircraft. The main idea is that during take-off the prop-rotors with their engines are positioned axis vertically like those of a helicopter in order to achieve vertical propulsive lift. At a desired height the prop-rotors are tilted successively horizontal towards conventional propeller airplane position where the lift capability is moved from the prop-rotors to the wings, and hence the cruise speed, range and fuel-economy are improved.

The research of tilt-rotor aircrafts began 1940. The XV-3 was built 1953 as a prototype for future improvements. In 1972 the developments of XV-15 started and were funded by NASA, U.S. army and Bell Helicopter Textron. The experience gained from these two was applied 1981 when the V22 was built.

The main drawback of the tilt-rotor aircrafts is that during hover, the rotors create an airstream that impinges on the wing and a part of the fuselage. This yields a significant loss of lift capability. This loss, or download, is estimated to be 10% of the aircraft weight and almost equal to the V-22 capability payload. In order to reduce this download, NASA, Bell and Boing started a research project on flow around a wing during hover. The result was a wing with a deflected flap that reduced the airstream exposed area and narrowed the wake. In optimization terms the flap deflection should be increased from its optimum but the airstream would separate and hence the download would increase. In this state AFC is the solution. With AFC the flow reattaches, the wake becomes narrower and the download is alleviated.

Truck-trailer

Truck-trailers have typically rectangular geometry on the rear-end with four perpendicular corners. This shape is mainly due to practical issues when transporting goods because it is desired to maximize the loading capacity. There are also legislations within EU that limit the total length of truck-trailer combinations. The dimensions of the trailer have been optimized according to these legislations. The cooperation between truck and trailer companies regarding to aerodynamics to improve the overall aerodynamics of truck-trailers has not had high priority. This present thesis is supported by both a truck and a trailer company in order to cooperate more closely. The idea is to put flaps on existing trailers that are not loading bearing and mount them with high angle. The naturally separated flow on the flap surface will be reattached using AFC and the drag will be decreased.

The use of AFC requires effective actuators that are capable to produce enough momentum. The net drag reduction or the efficiency of the AFC is then defined by

$$\eta_{AFC} = 1 - \frac{P_a}{P_s} \tag{1}$$

where P_a is the power required to generate the actuation and P_s is the power saved through drag reduction due to AFC. The present efficiency, η_{AFC}, is at least 80%.

Appended Papers

This thesis includes the following papers:

I M. El-Alti, P. Kjellgren and L. Davidson, 2008, On the Download Alleviation for the XV-15 Wing by Active Flow Control Using Large-Eddy Simulation, *ERCOFTAC WORKSHOP: Direct and Large-Eddy Simulation 7*, September 8-10, Trieste, Italy

II M. El-Alti, V. Chernoray, P. Kjellgren and L. Davidson, 2009, Experimental Investigation of a Simple Synthetic Jet Actuator for Active Flow Control Purposes, *Internal Report: Applied Mechanics, div. of Fluid Dynamics*, Chalmers University of Technology, March, Gothenburg, Sweden

III P. Kjellgren, M. El-Alti and L. Davidson, 2009, Download Alleviation of a Tilt-rotor Wing by Active Flow Control Strategies, *KATnet II Conference: Key Aerodynamic Technologies*, May 12-14, Bremen, Germany

IV M. El-Alti, P. Kjellgren and L. Davidson, 2009, Drag Reduction for Trucks by Active Flow Control of the Wake Behind the Trailer, *Accepted for publication at the 6th International Symposium on Turbulence, Heat and Mass Transfer*, September 14-18, Rome, Italy